INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

What role does climate change play in agricultural market uncertainty? An integrated assessment taking into account market-driven adjustments

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Abstract: Recent studies point to climate change being one of the long-term drivers of agricultural market uncertainty. To advance in the understanding of the influence of climate change on future agricultural market developments, we compare a reference scenario for 2030 with alternative simulation scenarios that differ regarding: (1) emission scenarios; (2) climate projections; and (3) the consideration of carbon fertilization effects. For each simulation scenario, the CAPRI model provides global and EU-wide impacts of climate change on agricultural markets. Results show that climate change would considerably affect agrifood markets up to 2030. Nevertheless, market-driven adaptation strategies (production intensification, trade adjustments) would soften the impact of yield shocks on supply and demand. As a result, regional changes in production would be lower than foreseen by other studies focused on supply effects.

Keywords: Bio-economic modelling, Climate change, Agricultural market uncertainty, Food security

JEL codes: C55, Q11, Q13

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1 Introduction

Agriculture is one of the most sensitive sectors to climate variations since production largely relies on climatic conditions (Adams *et al*, 1998, Gornall *et al*., 2010). Understanding the physical and socio-economic responses of the agricultural sector to future climate change scenarios is crucial for designing agricultural policies likely to have an impact on sustainable food security.

To deal with this challenge, a number of studies have analysed the effects of climate change on crop yields. These studies have shown that, while there is a small impact on global world food production, geographical differences are significant (Parry *et al*. 2004, Tubiello and Fischer 2006). Focusing on EU agriculture, most of the studies indicated a strong regional divergence: climate change may produce positive effects on average crop yields in northern Europe, but effects are likely to be mostly negative in southern Europe (Wolf and Van Diepen 1995, Donatelli *et al*. 2012).

Nevertheless, both biophysical and economic aspects need to be considered and combined in order to study the full range of climate change impacts on agriculture (Hillel and Rosenzweig, 2010). Seminal works by Tobey *et al*. (1992) and Reilly and Hohmann (1994) attempted to anticipate how climate change will affect future food production and prices. They concluded that the consequences of climate change on agriculture would be diffused throughout the world since the market acts as a significant adjustment mechanism. Recent global assessments of climate change impacts confirm these early findings (Nelson *et al*. 2010, Hertel *et al*. 2010, Lobell *et al*. 2011).

With regard to the European Union, a high proportion of the studies analysing the economic impacts of climate change focus on selected regions irrespective of changes in agricultural production elsewhere (Ciscar *et al*. 2011, Möller *et al*. 2011, Shrestha *et al*. 2013). It is only very recently that several authors have analysed climate impact on agriculture at the regional level in the EU while considering international trade (Blanco *et al*. 2014a, Frank *et al*. 2014).

The aim of this paper is to assess the influence of climate change on agriculture in terms of food prices and market balances up to 2030. The innovative side of our approach is to combine the biophysical and economic impacts of climate change both globally and at subnational level within the EU, based on the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change scenarios (IPPCC AR5), while taking into account the uncertainty with respect to CO_2 fertilization effects.

2 Methodology

2.1 Bio-economic modelling approach

In order to assess the biophysical and economic impacts of climate change on agriculture, we enter exogenous yield changes from biophysical simulations (WOFOST and LPJmL models) into the CAPRI agro-economic model, capable of predicting global and EU-wide impacts on agrifood markets. As long-term macroeconomic and agricultural projections are highly uncertain, we refrain from using a very long-range projection period. Thus, the time horizon chosen for this study is 2030. In our analysis we compare a reference scenario for 2030 (current climate or 2010 climate) with several simulation scenarios (representing different crop yield projections over the next 20 years).

CAPRI (Common Agricultural Policy Regionalized Impact Modelling System) is a partial equilibrium model for the agricultural sector developed to assess the impact of the Common Agricultural Policy (CAP) and trade policies from global- to regional-scale with a focus on the European Union (Britz and Witzke, 2012). It is a comparative static and spatial equilibrium model solved by iterating supply and market modules:

- The supply module consists of a set of regional agricultural supply models, covering all EU regions (NUTS 2 level), Norway, the Western Balkans and Turkey. This module captures the details of farming decisions for all the activities covered by the economic accounts for agriculture (EAA), as well as the interactions between production activities and the environment. Major outputs of the supply module include crop and livestock activity levels, yields, input use, farm income, nutrient balances and GHG emissions.
- The market module is a global spatial multi-commodity model, where about 50 commodities – including primary and secondary agricultural products – and around 40 trade blocs (individual countries or country groups) are modelled as a constrained system of equations. Major outputs of the market module include bilateral trade flows, market balances and producer and consumer prices for the agricultural commodities and world country aggregates.

The CAPRI baseline describes the agricultural situation in a future year, the so-called simulation year, based on the situation in historical years and expected developments from the base year to the simulation year. A distinguishing feature of the CAPRI baseline is its sub-EU regional resolution, down to regions at NUTS 2 level within EU-28 member states. Therefore, the CAPRI baseline reflects the likely developments in agricultural markets for the year 2030 time horizon on a global to regional scale under exogenous assumptions (population growth, technological change, GDP growth, inflation rate, exchange rate, crude oil price) and a status quo policy setting. For a detailed description of the baseline scenario as well as the baseline results, see Frank et al. (2014).

2.2 Definition of simulation scenarios

We defined different scenarios to embrace the whole variability of future agricultural market developments due to uncertainty about future crop yields, caused by climate change and carbon fertilization effects. The scenarios are based on a plausible combination of representative concentration pathway (RCP) and shared socioeconomic pathway (SSP) taken from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. The RCP (climate signal) represents the future mitigation and adaptation challenges as the level of radiative forcing, and the SSP denotes mitigation and adaptation capacities “but also system exposure to climate impacts” (von Vuuren *et al.* 2011). The RCPs correspond to four different possible trajectories of future greenhouse gases concentration, expressed by the level of possible radiative forcing values (2.6, 4.5, 6 and 8.5 W/m^2). Regarding the SSPs, there are five different projections: SSP 1 (sustainability), SSP 2 (middle of the road), SSP 3 (fragmentation), SSP 4 (inequality) and SSP 5 (conventional development). We chose to use SSP 2 since the socio-economic conditions are developing rather sluggishly. Therefore, the selected pathway represents a storyline consistent with the socio-economic developments observed in recent decades.

The chosen time horizon is 2030, as our study sets out to analyse the long-term impacts of climate change on agrifood markets.

The scenarios differ with respect to:

1) Climate projections according to different climate conditions forecasted by two different general circulation models (GCM): HadGEM2-ES (Hadley Centre, UK Meteorological Office) and IPSL-CM5A-LR (Institute Pierre-Simon Laplace, France). The reason for using more than one GCM was to include all possible different climate projections in order to take into account the whole spectrum of uncertainty. These two GCMs were selected because they provided data for the types of crop yield simulation models used.

2) Two different RCPs (4.5 and 8.5) used to compute the two GCMs for the climate change scenario. The employed RCPs reflect two radiative forcing levels that represent different anthropogenic-induced climate challenges: a high level according to RCP 8.5 (highest scenario, with a radiative forcing of 8.5 W/m^2 by 2100 and a subsequent upward trend) and a lower level according to RCP 4.5 (medium-low scenario targeting stabilization at 4.5 W/m^2 after 2100).

3) The CO_2 fertilization effect surrounding which there are also major uncertainties. Thus, all biophysical simulations were performed with and without the carbon fertilization effect.

Table 1: Scenario characterization

Code	RCP	GCM	Crop model	CO_2 effects
Reference	Present climate	None	None	None
HADGEM2_8.5_CO2	RCP 8.5	HadGEM2	WOFOST- LPJmL	Full CO_2
IPSL_8.5_CO2	RCP 8.5	IPSL	WOFOST- LPJmL	Full CO_2
HADGEM2_8.5_noCO2	RCP 8.5	HadGEM2	WOFOST- LPJmL	No CO_2
IPSL_8.5_noCO2	RCP 8.5	IPSL	WOFOST- LPJmL	No CO_2
HADGEM2_4.5_CO2	RCP 4.5	HadGEM2	WOFOST- LPJmL	Full CO_2
IPSL_4.5_CO2	RCP 4.5	IPSL	WOFOST- LPJmL	Full CO_2
HADGEM2_4.5_noCO2	RCP 4.5	HadGEM2	WOFOST- LPJmL	No CO_2
IPSL_4.5_noCO2	RCP 4.5	IPSL	WOFOST- LPJmL	No CO_2

For EU regions, the impact of climate change and carbon fertilization on crop yields was simulated using the WOFOST (World Food Studies) model, developed at

Wageningen University (Van Diepen et al. 1989, Boogaard et al. 1998). We used yield changes at a 25 km grid resolution all over the EU for nine of the most grown crops (wheat, maize, barley, rye, rice, field beans, rapeseed, sunflower, sugar beet and potato) across the 1990-2060 period. The results of the simulations were aggregated at regional level (NUTS 2) using regional statistics on crop areas. For more details on the biophysical simulations, see Blanco et al. (2014b).

For non-EU countries, we used crop yield projections supplied by the ISI-MIP modelling initiative[1]. In particular, we used yield projections by the LPJmL model (Bondeau et al. 2007) for the 1990-2060 period and the following seven crops: wheat, maize, rice, rapeseed, soybean, sugar beet and sugar cane. LPJmL projections were available for both rainfed and irrigated crops and the eight simulation scenarios specified above. Statistics on crop areas were used to aggregate grid-level data to the spatial units of the global CAPRI model (trade blocs).

3 Results and discussion

In order to assess the influence of climate change on agriculture in terms of food prices and market balances, we compared the baseline with the different scenarios outlined above. The baseline represents current climate and SSP2, which assumes a continuation of recent trends up to 2030 (Frank et al. 2014).

The analysis focuses on climate change impacts on global and regional production for four main crops: wheat, maize, soybean and rapeseed. To evaluate the role of trade adjustment we particularize it for wheat.

3.1 Climate-induced effects on global agricultural production and prices

Results from biophysical models show variations in crops yields as a consequence of climate change. Analysing the different scenarios worldwide, we observe that yields increase when CO_2 effects are considered and decrease when carbon fertilization is left out of the equation, except for the HADGEM2 scenario with RCP 4.5 and without CO_2 effects, where yields for maize, rapeseed and soybean rise slightly.

[1] Grid data are available for download from PIK (http://esg.pik-potsdam.de/esgf-web-fe/)

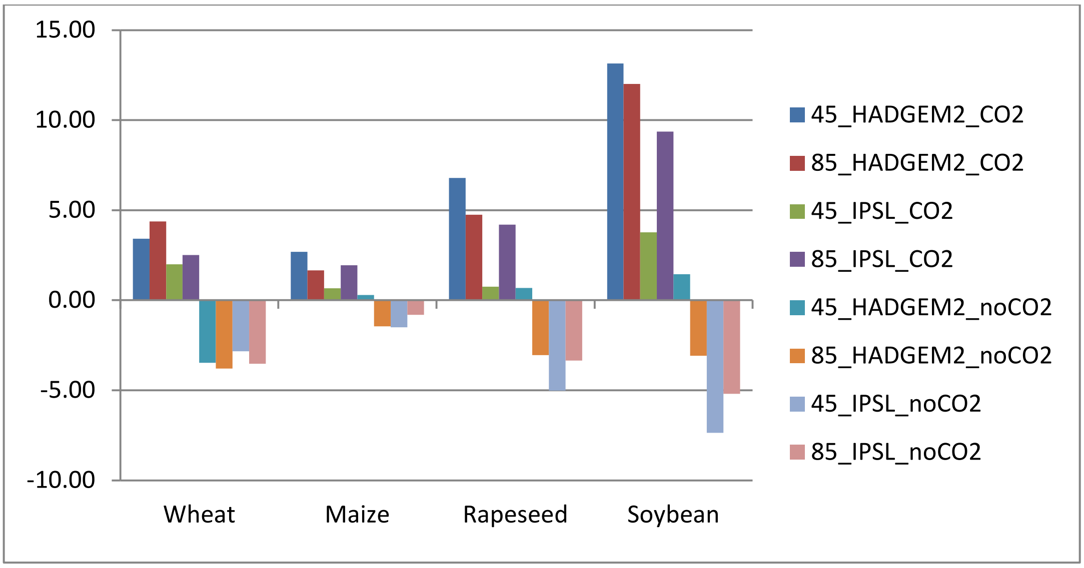

Figure 1: LPJmL-simulated world changes in yields (2010 - 2030)

For production, Figure 2 shows the scenarios for maize and rapeseed, with and without the carbon fertilization, conform to a general pattern: production increases with full fertilization and the opposite applies without carbon fertilization. Wheat also follows this pattern with exception of scenario HADGEM2 RCP 4.5 without CO_2 effects which presents a modest increase in production. Soybean production increases in all scenarios except for scenarios IPSL without carbon fertilization.

With regards to the variations between the scenarios based on the use of different RCP (4.5 and 8.5), the highest pathway does not appear, surprisingly, to yield the highest production level in the case of full carbon fertilization. In the case of the HADGEM2 projection, the amount produced under a 4.5 RCP is greater than yields for an 8.5 RCP. This does not apply in the IPSL model. Therefore, the use of different RCPs proves to have mixed results.

The variability of the reported results corroborates the need to use different climate models, as well as different RCPs to comprehend and unveil uncertainty.

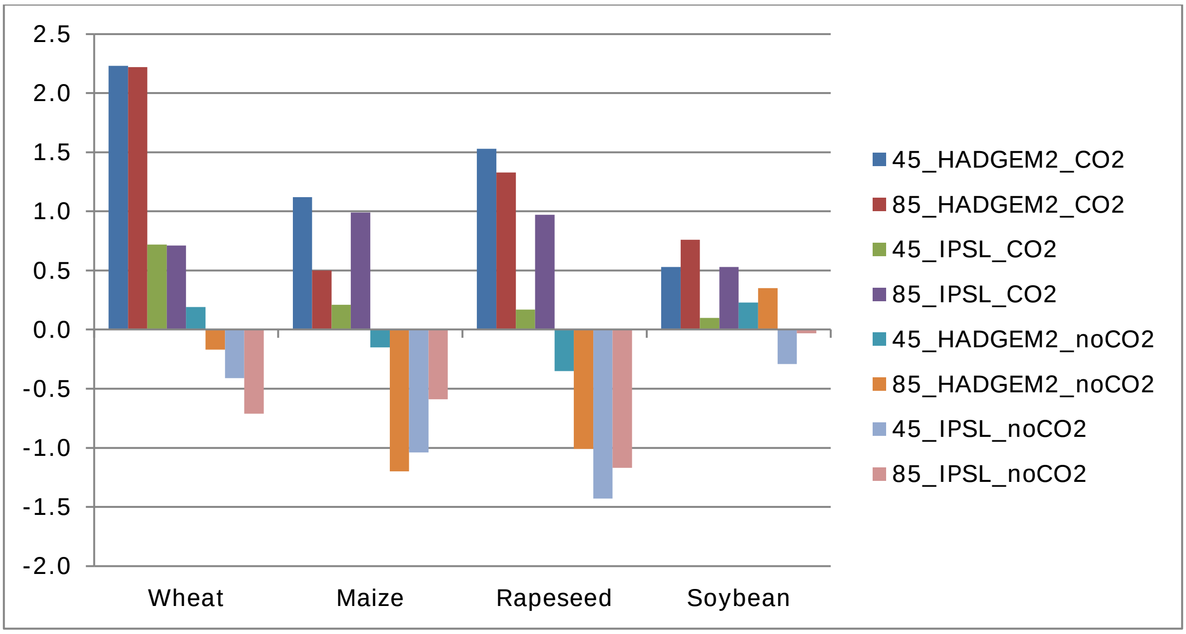

Figure 2: World production (% change from the baseline)

With respect to prices, small variations in production appear to have big impacts on prices (Figure 3). A possible explanation is the low elasticities of supply and demand for most agricultural commodities. The price of wheat, maize and rapeseed appears to rise (fall) when production decreases (increases), although this is not always the case for soybean.

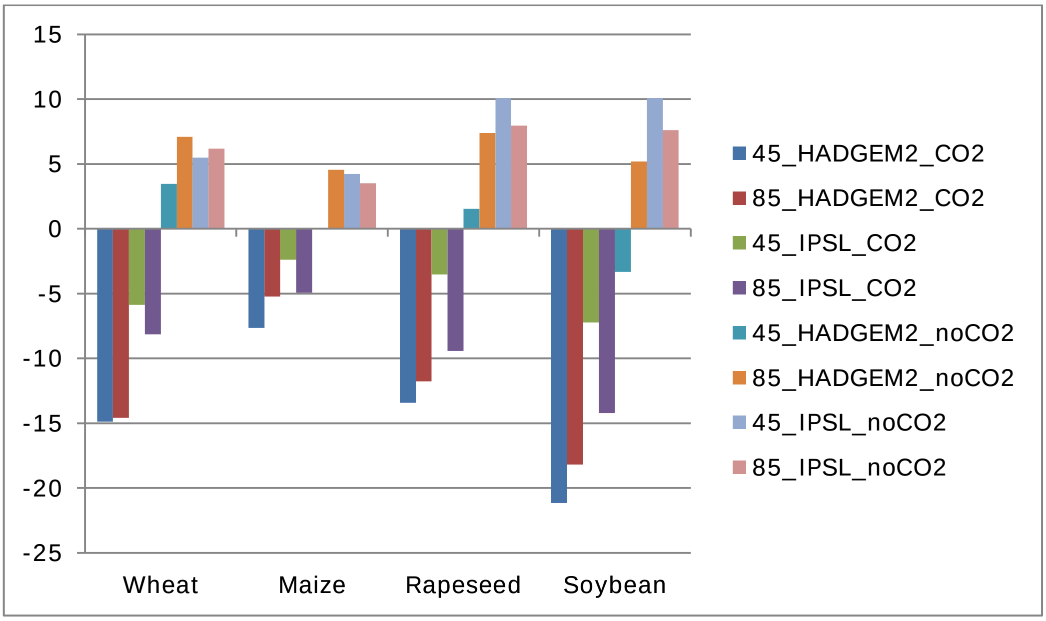

Figure 3: World producer prices (% change from the baseline)

3.2 Climate-induced effects on regional agricultural production

Climate change effects are different throughout the world, and we carry out a more thorough geographical analysis. Thus, we have studied the production variations of the main exporters and importers of each crop.

The major net exporters of wheat are the European Union (EU-28), the USA, Canada and Australia and New Zealand, with the major importers being the Middle East and North Africa (MENA)[2], South-East Asia (SEA)[3], Sub-Saharan Africa (SSA) and Brazil (BRA).

A common feature of wheat is that a major increase or decrease in production is caused by changes of the same sign in yields. Wheat production is determined by its own yields rather than by price variation, which might be a consequence of an inelastic supply.

Figure 4 below shows that Canada presents the most significant variability in production, ranging from -9% in the IPSL projection without the CO_2 effect and with a 4.5 RCP to 13% in the HADGEM2 scenario with the CO_2 effect and a 4.5 RCP. This variation corresponds to changes in yield. In the case of the EU, we have observed that an increase in production is related to a 4.5 RCP, whereas a decrease is caused by the 8.5 RCP, irrespective of carbon fertilization.

[2] Middle East and North Africa (MENA) includes Middle East, North Africa and Turkey.

[3] South-East Asia (SEA) consists of Indonesia, Malaysia, South Korea, Vietnam, Thailand, Japan, Taiwan

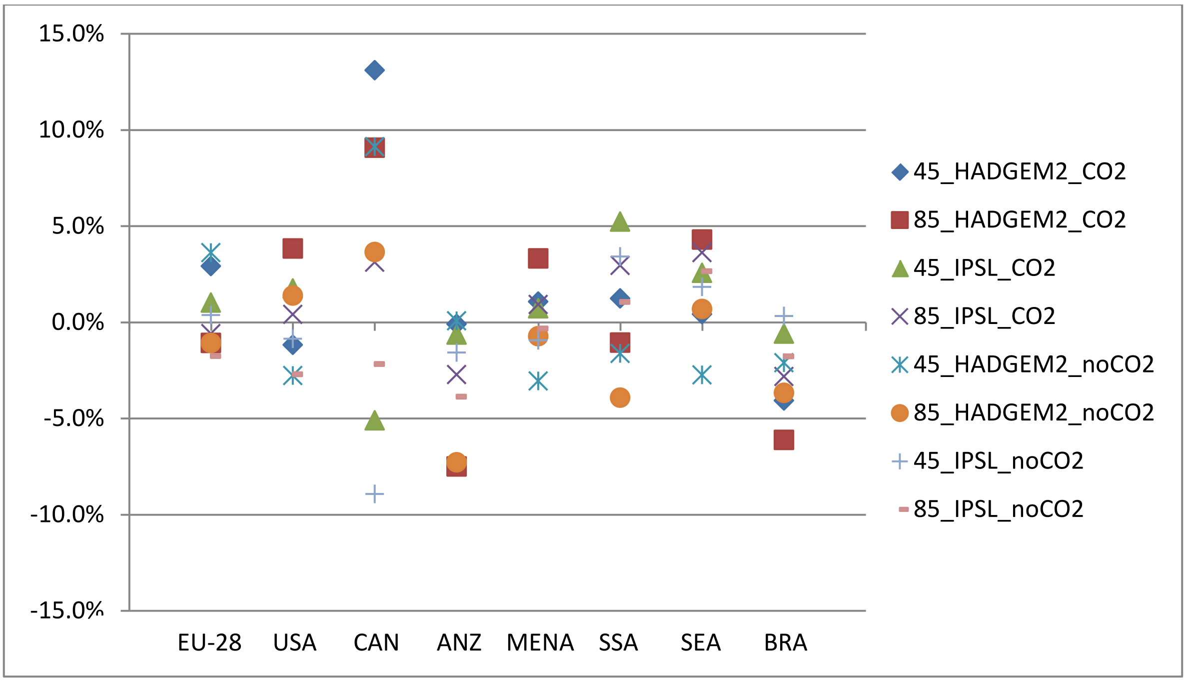

Figure 4: Wheat production (% change from the baseline)

The key maize exporters in the world are the USA, Argentina and Brazil. The main importers that we identified are South and Central America (OSA) -excluding Brazil and Argentina -, SEA and MENA.

Following the pattern of wheat, maize production also appears to be more influenced by yields than by global prices, with Argentina and the USA having the biggest variability in production.

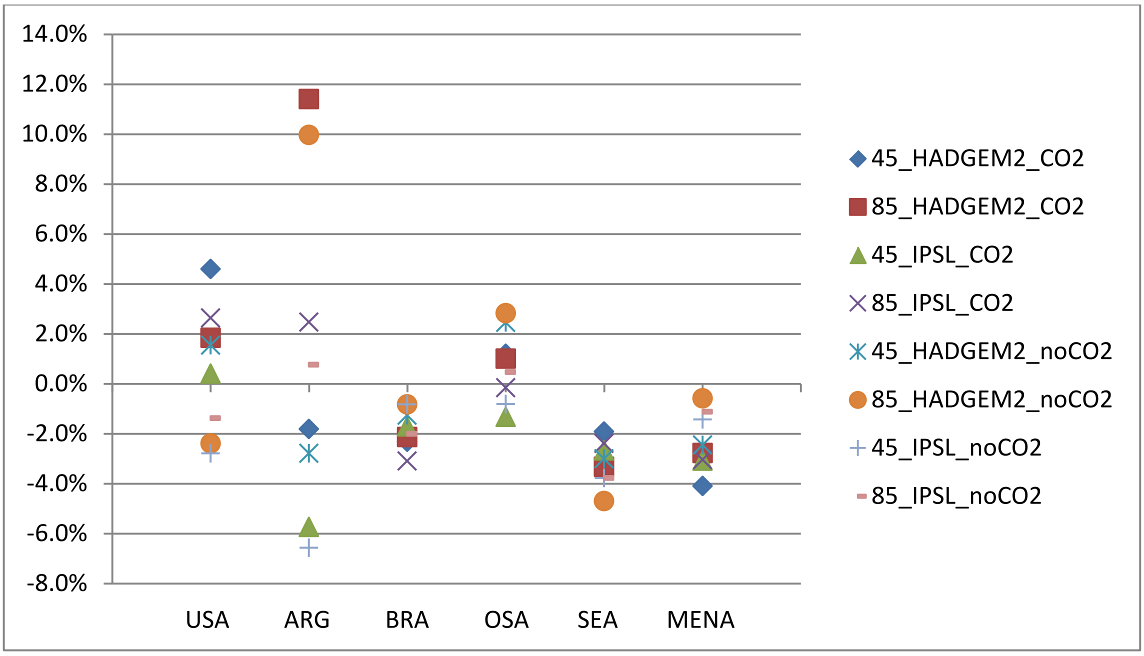

Figure 5: Maize production (% change from the baseline)

With regard to soybean, the main exporters are the USA, Brazil and Argentina, while the major importers are the China, EU-28 and SEA.

As shown in Figure 6, different scenarios produce extreme values: the highest positive variation is observed for a 4.5 RCP, except in Argentina where the highest change coincide with 8.5 RCP. Taking into account yield changes (Annex 1), we find that these are significantly higher in the case of Argentina and USA when carbon fertilization effects are taken into account. This suggests that there is a price-related adjustment in production (Figure 3) since the world soybean market price increases when CO_2 effects are disregarded.

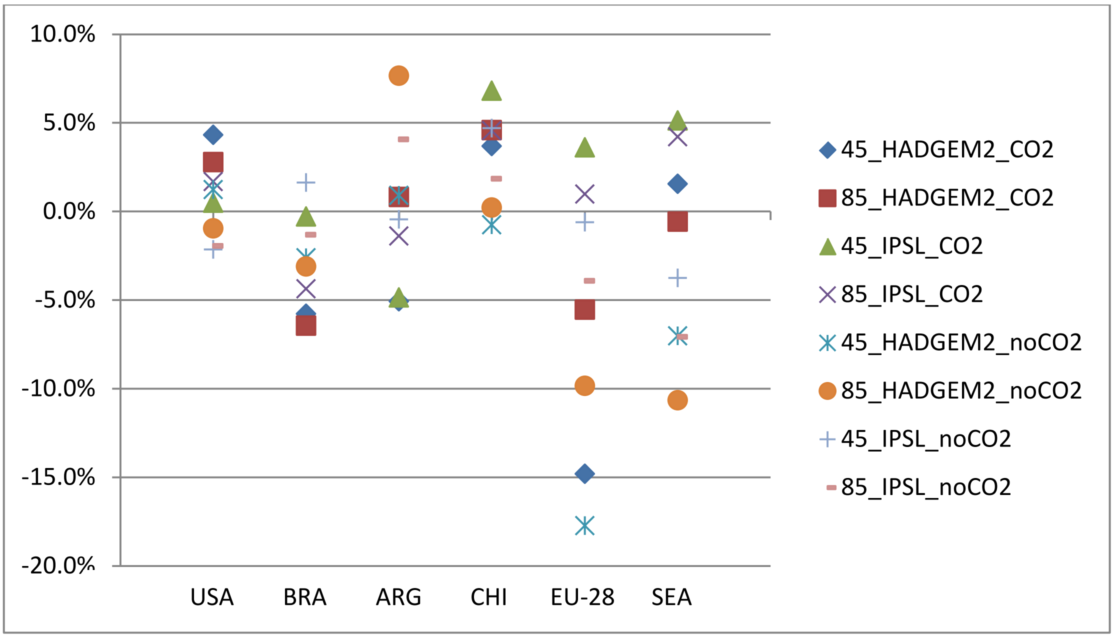

Figure 6: Soybean production (% change from the baseline)

In the case of rapeseed, Canada, EU-28 and Australia and New Zealand are the main exporters, whereas China, EU-28 and SEA are the main importers.

Figure 7 highlights that, contrary to expectations, rapeseed production in Canada increases most when carbon fertilization is not considered. This could be explained by taking into account changes in market prices, as illustrated in Figure 3, where rapeseed prices rise when CO_2 effects are not taken into account.

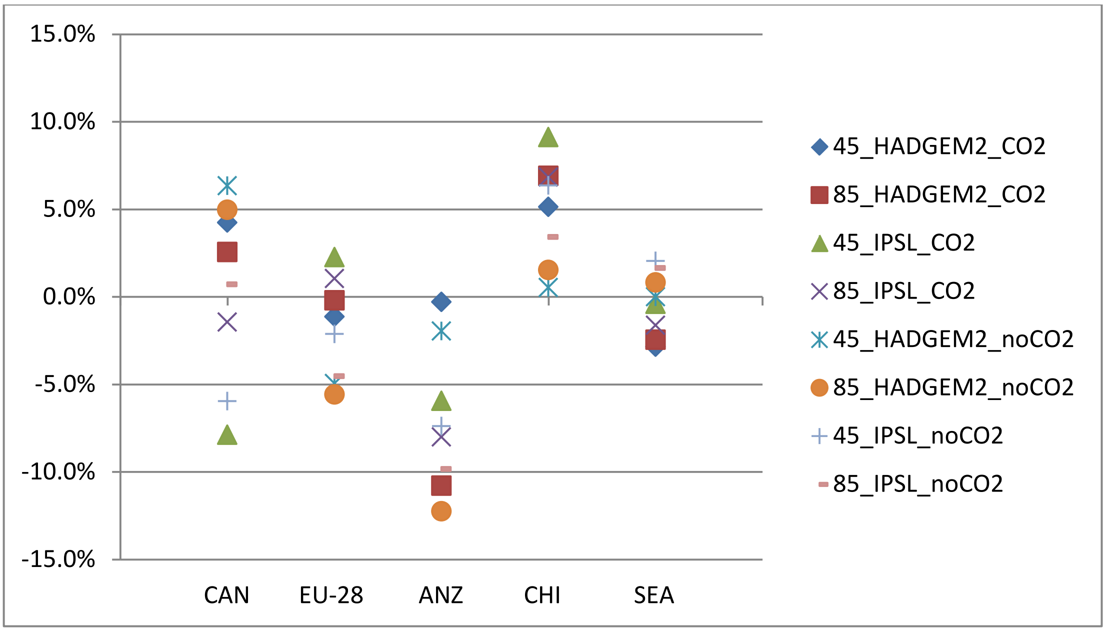

Figure 7: Rapeseed production (% change from the baseline)

The level of production is not only determined by changes in yields, but also by global price variations. Hence, we observed that the production of wheat and maize, which can be considered staple foods, follows the pattern of changes in yields, whereas soybean and rapeseed production varies significantly with the global price level.

On the other hand, we also observed that extreme changes in production level are not always determined by the highest RCP, as we might have expected.

3.3 The role of trade adjustments

To illustrate how trade adjustments counterbalance the effects of climate change on production, we focused on the wheat trade, considering the European Union and its trading partners. We focussed the analysis for one GCM, HADGEM2, with and without CO_2, for a 4.5 and 8.5 RCP, since it highlights sizeable variations in global production (Figure 2).

As explained above, wheat production in the European Union increases when considering RCP 4.5 with and without CO2 but decreases for RCP 8.5 (Figure 4). Surprisingly, increased production results in import increases, whilst exports reduce, especially for those scenarios which consider carbon fertilization. This remarked decline in wheat exports is related to a drop in the price of this product in scenarios considering CO2 effects (Figure 3), but also to an increase in wheat demand. Therefore, we observed a significant increase in the use of wheat for animal feed, which varies between 4 and 16%, whereas human consumption rises by only 0.01-0.06% for all scenarios with respect to the baseline. As shown in Figure 8, this change in wheat demand is linked to maize demand, since wheat acts as a substitute of maize, whose production in the EU is negatively affected by climate change.

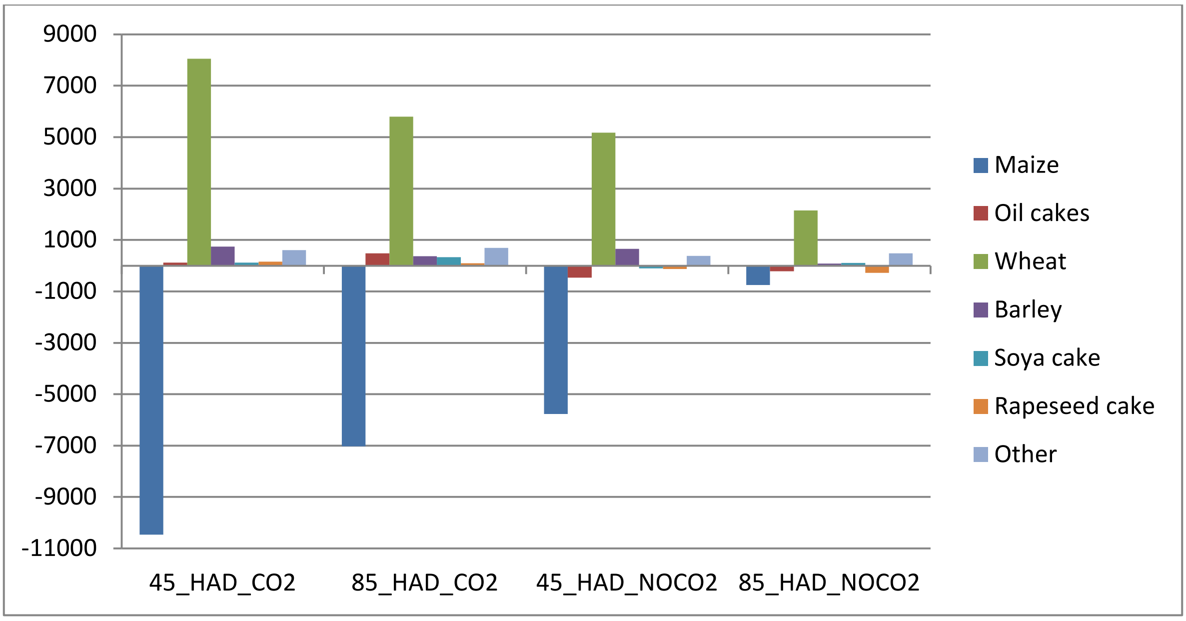

Figure 8: Feed use in European Union by product (% change from baseline)

Trade acts as a means of adjustment to changes in production and demand of wheat in the EU-28. Hence, the EU-28 increases its imports and reduces exports in response to the increase in wheat demand for feed (Figure 9). The significant decline in exports from EU-28 to MENA and SSA is compensated mainly by an increase in imports in these regions from Canada (Annex 2).

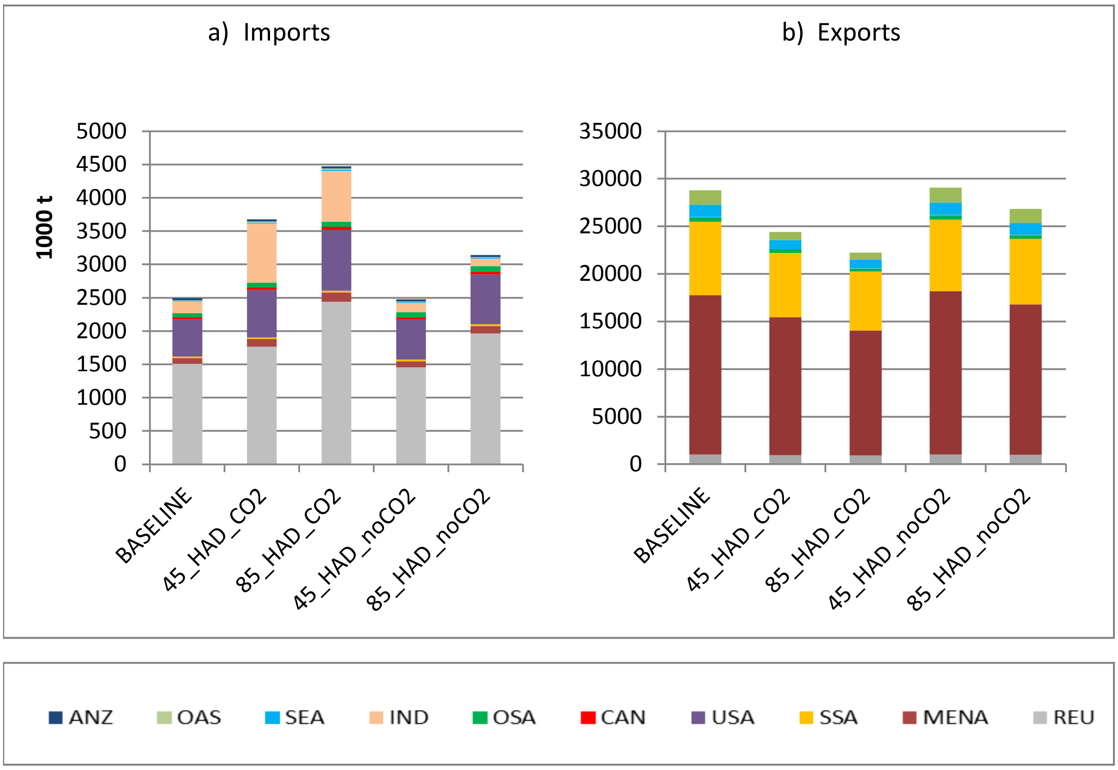

Figure 9: Wheat trade in European Union: changes in a) imports and b) exports from baseline (values in 1000 t).

4 Conclusions

In this study, we analyse the role of climate change as a driver – and a source of uncertainty – of the evolution of agrifood markets. We apply a bio-economic approach to assess the socio-economic effects of climate change on agriculture, providing both a global analysis and an analysis broken down by the main traders. To account for uncertainty, we analyse the RCP8.5 and RCP4.5 IPCC emission scenarios for the 2030 horizon under several simulation scenarios that differ with respect to: (1) the climate projection, and (2) the influence of CO_2 effects.

Climate change impacts on crop yields vary widely across regions, crops, RCPs and CO_2 scenarios. By comparing simulation scenarios, we find that the carbon fertilization effect can influence the direction of effects. Different RCPs can determine the magnitude of the climate change impact; therefore, the highest range of variation is not always related to the highest RCP. Economic simulations demonstrate that crop prices will react to yield changes, attenuating the effects of climate change at the global level, but having divergent effects across regions and sectors depending on the magnitude and direction of yield changes and their impact on productivity.

The results of this study suggest that agrifood market projections up to 2030 are very sensitive to changes in crop productivity and, therefore, to the uncertainties linked to climate change. They also show that market forces and changes in competitive advantages can reverse the effects of yield changes.

Acknowledgments

This study has been funded under the ULYSSES project, EU 7th Framework Programme, Project 312182 KBBE.2012.1.4-05. The views expressed are those given and presented by the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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Annex 1. LPJmL and WOFOST simulated world changes in yields (2010 - 2030) for wheat, maize, soybean and rapeseed

WHEAT	45_HAD_CO2	85_HAD_CO2	45_IPSL_CO2	85_IPSL_CO2	45_HAD_noCO2	85_HAD_noCO2	45_IPSL_noCO2	85_IPSL_noCO2
EU28	6.1	2.0	2.5	1.8	0.3	-5.2	-2.9	-5.3
USA	0.1	6.1	2.4	1.2	-4.9	-0.4	-2.8	-5.2
CAN	14.5	10.7	-4.3	4.0	7.9	2.2	-10.3	-3.9
ANZ	3.4	-4.9	0.6	-0.8	-1.6	-11.0	-4.4	-7.1
JAP	2.5	6.7	3.2	4.6	-4.0	-1.0	-0.1	0.5
BRA	3.4	1.5	1.8	1.6	-4.6	-8.9	-5.5	-8.1
MAIZE	**45_HAD_CO2**	**85_HAD_CO2**	**45_IPSL_CO2**	**85_IPSL_CO2**	**45_HAD_noCO2**	**85_HAD_noCO2**	**45_IPSL_noCO2**	**85_IPSL_noCO2**
USA	6.0	2.3	0.2	3.4	1.6	-3.8	-4.2	-2.1
ARG	1.5	13.8	-5.7	4.0	-3.5	7.4	-10.	-1.7
BRA	-1.7	-1.8	-2.6	-3.3	-2.4	-2.8	-3.2	-4.2
MEX	8.0	5.1	-2.1	2.1	5.6	2.2	-5.0	-1.7
JAP	2.0	1.1	2.0	4.1	0.1	-1.0	1.2	2.8
SOYBEAN	**45_HAD_CO2**	**85_HAD_CO2**	**45_IPSL_CO2**	**85_IPSL_CO2**	**45_HAD_noCO2**	**85_HAD_noCO2**	**45_IPSL_noCO2**	**85_IPSL_noCO2**
USA	14.8	11.5	5.1	8.5	4.3	-2.3	-5.1	-4.6
BRA	6.0	2.9	3.8	2.6	-5.8	-12.3	-7.1	-11.2
ARG	13.4	25.6	-8.0	14.7	-1.4	6.1	-22.7	-6.0
EU28	4.5	7.3	7.6	9.4	-2.8	-1.8	1.0	1.1
CHI	10.8	10.0	9.0	9.1	1.2	-1.8	0.6	-1.5
RAPE	**45_HAD_CO2**	**85_HAD_CO2**	**45_IPSL_CO2**	**85_IPSL_CO2**	**45_HAD_noCO2**	**85_HAD_noCO2**	**45_IPSL_noCO2**	**85_IPSL_noCO2**
CAN	15.6	12.1	-7.2	5.1	8.3	2.5	-13.6	-3.7
EU28	1.2	1.8	3.8	4.0	-6.2	-7.7	-3.4	-5.5
ANZ	4.9	-6.8	-5.3	-5.1	-1.0	-14.0	-10.9	-12.5
CHI	6.1	7.2	8.3	7.7	0.4	-0.2	2.8	0.7

Annex 2. Wheat exports from major exporters (% change from baseline). Baseline values in 1000 t.

From EU to					
	Baseline	45_Had_CO_2	85_Had_CO_2	45_Had_noCO_2	85_Had_noCO_2
REU	1025	-5.7%	-9.4%	-1.0%	-4.0%
MENA	16739	-13.5%	-21.5%	2.6%	-5.5%
SSA	7715	-12.3%	-19.6%	-2.8%	-10.6%
OSA	463	-19.9%	-39.7%	0.1%	-21.8%
IND	32	-84.9%	-81.5%	22.3%	63.9%
SEA	1300	-25.7%	-29.4%	-0.2%	-5.0%
OAS	1505	-44.3%	-48.3%	4.9%	-0.6%
From USA to					
	Baseline	45_Had_CO_2	85_Had_CO_2	45_Had_noCO_2	85_Had_noCO_2
EU28	556	27.4%	64.4%	7.1%	34.5%
REU	5	52.0%	66.4%	-1.6%	6.5%
MENA	1691	19.0%	47.3%	2.2%	24.0%
SSA	3181	11.0%	24.4%	-0.6%	10.2%
CAN	312	-25.8%	-8.7%	-24.4%	-7.5%
BRA	895	-4.4%	-2.8%	-1.4%	0.0%
OSA	8584	0.5%	5.0%	-4.4%	-0.6%
SEA	11180	-1.1%	2.7%	-0.1%	3.0%
OAS	3438.1	-32.8%	-30.2%	-1.8%	2.6%
From Canada to					
	Baseline	45_Had_CO_2	85_Had_CO_2	45_Had_noCO_2	85_Had_noCO_2
EU28	29	42.2%	54.2%	34.7%	45.9%
REU	80	32.0%	28.4%	-0.7%	1.1%
MENA	12438	20.1%	14.5%	14.0%	6.1%
SSA	1141	44.2%	41.9%	26.1%	20.5%
USA	3123	2.0%	-9.7%	19.4%	9.4%
BRA	524	36.8%	15.6%	20.2%	-1.9%
OSA	3548	23.5%	17.3%	10.2%	2.8%
SEA	806	24.0%	19.1%	23.8%	15.0%
OAS	383	-21.1%	-21.8%	33.2%	23.3%
From Australian and New Zealand to					
	Baseline	45_Had_CO_2	85_Had_CO_2	45_Had_noCO_2	85_Had_noCO_2
EU28	28	14.4%	8.7%	11.3%	9.6%
MENA	944	-6.0%	-22.7%	-8.9%	-23.3%
SSA	2259	8.3%	-9.3%	1.3%	-14.1%
SEA	9707	-2.2%	-8.9%	0.6%	-5.9%
OAS	2028	-1.1%	-26.6%	5.1%	-19.9%

* Country aggregates: Rest of European Union (REU), Middle East and North Africa (MENA), Sub-Saharan Africa (SSA), Canada (CAN), Brazil (BRA), Argentina (ARG), Other South and Central America (OSA), South East Asia (SEA), India (IND), China (CHI), Other Asia (OAS).